(54) **Title:** GRINDING OF CUTTING TOOLS WITH A CONSTANT RAKE ANGLE
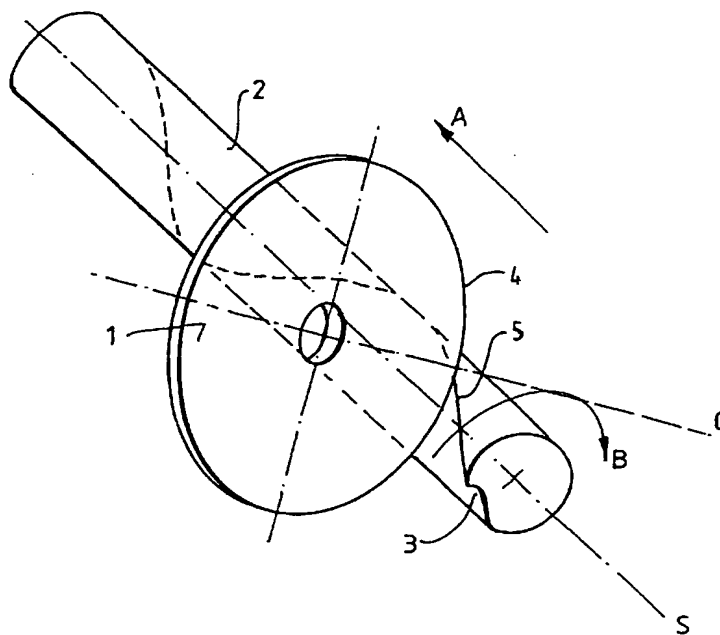
(57) **Abstract:** A method of grinding a surface of a flute (3) on a cutting tool (2) over a range of tool diameters using a grinding machine having a rotatable grinding wheel (1) that is adapted to move relative to the cutting tool. The method includes determining a machine path of the grinding wheel and rotating the grinding wheel and moving it along the machine path to grind a flute surface having a substantially constant rake angle. The invention also relates to a CNC tool grinding machine and a cutting tool.

WO 02/20216 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

GRINDING OF CUTTING TOOLS WITH A CONSTANT RAKE ANGLE

This invention relates to the grinding of cutting
tools. It is particularly concerned with a method of
5   operating a computer numerically controlled (CNC) grinding
machine to produce cutting tools with flute surfaces, which
maintain a constant rake-angle over a range of diameters, and
to such cutting tools produced by the method.

10   Rotary cutting tools generally have a series of
helical blades. These blades are generally formed by two
adjoining faces, a leading face (e.g. a flute surface) and a
trailing face (e.g. a relief surface). The adjoining faces in
turn form a crest with a sharp edge of generally smooth
15   helical configuration. This edge is usually called the
cutting edge.

The performance of such cutting tools depends in
parts on the geometric configuration of the blade's leading
20   face (e.g. flute surface), and in particular depends on the
angle the leading face forms with the surface, which is being
machined. This angle is measured in terms of the angle
between the tangent of the leading face in radial direction
and the surface normal of the machined work-piece surface.
25   This angle is usually called the rake angle or hook angle.
Said cutting tool performance is very sensitive to variations
of the rake angle. The rake angle present at the cutting edge
of a cutting tool is a property of the geometry of the
blade's leading face.
30
One class of cutting tools comprises cutting
profiles, which vary in diameter over the length of the tool.
Such variations may be smooth and continuous or appear in
discrete steps. This class of cutting tools is usually
35   referred to as Step Tools or Profile Tools. The blades of
such Step Tools often comprise a single leading face
extending over the full length of the cutting profile. The

rake angle at any point of a cutting edge of any blade of
such tools depends on the geometry of the leading face. With
existing grinding methods for CNC tool and cutter grinding
machines it is not possible to maintain a constant hook or
5   rake angle over the length of the cutting edge of one blade
in such Step or Profile Tools.

One other class of cutting tools comprises cutting
profiles, which are of generally cylindrical or conical
10   shape. This class of cutting tools is usually referred to as
End Mills or Milling Cutters. The economy of cutting tools of
this class depends on the ability to re-sharpen the cutting
tool. Such tools are usually re-sharpened by re-grinding the
outer diameter, reducing the radius of the tool. This
15   reduction in diameter has the effect that a different region
of the leading face adjoins the cutting edge, said region
determining the rake angle at the cutting edge. For flutes
ground with existing prior art, each incremental re-
sharpening operation will produce a different rake angle at
20   the cutting edge.

There have previously been proposals to fit inserts
into milling cutters with an edge of the insert forming the
cutting edge of the cutter. With such inserts it may be
25   possible for the leading face or flute surface to have a
constant hook or rake angle over a range of diameters.
However, such milling cutters can be expensive to
manufacture, possess cutting speed limitations due to
inherent material imbalance and hitherto it has not been
30   possible to maintain the constant hook or rake angle when
grinding the outer diameter to re-sharpen the milling cutter
or cutting tool.

It is therefore desirable to provide a method and
35   CNC tool grinding machine for producing an improved geometry
of leading faces (flutes) of cutting tool blades and that
said improved geometry being of such nature that it produces

a specified and controlled constant rake angle, independent of a varying cutting profile or diameter of the cutter, which is being ground.

5   According to one aspect of the present invention there is provided a method of grinding a surface of a flute on a cutting tool over a range of tool diameters using a grinding machine having a rotatable grinding wheel that is adapted to move relative to the cutting tool, the method

10   including:
          determining a machine path of the grinding wheel; and
          rotating the grinding wheel and moving it along the machine path to grind a flute surface having a

15   substantially constant rake angle.

      According to another aspect of the invention, there is provided a method of operating a CNC tool grinding machine to grind the flute surface of a cutting tool, the tool

20   grinding machine having at least one rotatable grinding wheel movable relative to the said method including the programming of the CNC machine with at least one path for the grinding of at least one flute, wherein said method produces a flute geometry, which maintains a substantially constant hook or

25   rake angle over a range of diameters.

      According to another aspect of the invention, there is provided a CNC tool grinding machine, having at least one rotatable grinding wheel movable relative to the cutting tool

30   for grinding at least one flute surface in the cutting tool, the machine being programmed with at least one path for the at least one grinding wheel which is calculated to grind said flute surface maintaining a substantially constant hook or rake angle over a range of diameters of the flute surface.

35
      According to a further aspect of the invention, there is provided a cutting tool having at least one flute

surface produced by the method or by a CNC tool grinding
machine in accordance with one of the preceding aspects of
the invention, whereby said flute surface has a substantially
constant hook or rake angle over a range of diameters of the
5   flute surface.

        Preferably, the cutting tool is produced by
calculating the wheel geometry of a grinding wheel required
to grind a flute surface with a substantially constant hook
10   or rake angle, dressing a grinding wheel in accordance with
the calculated wheel geometry, and grinding the cutting tool
with the dressed grinding wheel in accordance with a
programmed path generated by the CNC tool grinding machine.

15   The wheel geometry is preferably calculated from a
three dimensional (3D) model of the flute geometry for a
flute surface with the required constant rake-angle in an
inverse solving module. The inverse solving module preferably
also receives data representing the programmed path for the
20   grinding wheel and calculates machine settings for
controlling movement of the grinding wheel along the
programmed path to grind the flute surface with the
substantially constant hook or rake angle.

25   The CNC tool grinding machine preferably includes
input means for entering constant hook or rake cross-section
parameters into a programmable control unit of the machine.
Flute twist parameters and machine path parameters, such as
wheel radius, phase angle and pivot angle, are preferably
30   also input into the programmable control unit (PCU). The
constant hook or rake cross-section parameters are preferably
used to generate flute cross-section data and the 3D flute
geometry is preferably calculated from the flute cross-
section data and the flute twist parameters.
35

        The programmed path is preferably calculated from
the constant hook cross-section parameters, the machine path

parameters and the flute twist parameters.

According to another aspect of the invention there
is provided a method of generating a required wheel geometry
5   for dressing a grinding wheel for grinding a flute surface
having a substantially constant hook or rake angle over a
range of diameters, said method including the steps of,
generating a three-dimensional (3D) flute geometry for the
required flute surface, generating a programmed path for the
10   grinding wheel to grind the flute surface, and calculating
the required wheel geometry for the grinding wheel from the
3D flute geometry and the programmed path.
Preferably, the method also includes the step of
generating a two-dimensional (2D) flute cross-section
15   geometry, providing for the constant rake or hook angle.

According to yet another aspect of the invention
there is provided a computer program for use with a CNC tool
grinding machine, said computer program comprising flute
20   geometry generating means to generate three-dimensional flute
geometry data for a flute surface having a substantially
constant hook or rake angle over a range of diameters, path
generating means for generating a programmed path for a
grinding wheel to grind said flute surface with the
25   substantially constant hook or rake angle, and inverse
solving means for calculating the required wheel geometry for
the grinding wheel to grind said flute surface with the
substantially constant hook or rake angle over a range of
diameters.
30
In some cases, the required wheel geometry to grind
a flute with a constant hook or rake angle over a range of
diameters generated by the inverse solving module in the
present invention may be difficult to dress on a grinding
35   wheel. In this case, the present invention may include an
interactive, iterative method and system for finding an
optimum compromise between the wheel geometry's suitability

for dressing and the flute geometry's performance
characteristics, while maintaining that portion of the flute
geometry which provides for the substantially constant hook
or rake angle over a range of diameters.

5

        In the interactive, iterative method, the required
wheel geometry for grinding a flute with a constant hook or
rake angle is generated and both this geometry and the flute
geometry may be displayed to the operator. The user can then
10   modify the wheel geometry to a shape that is easier to dress
on a grinding wheel. Both the originally generated wheel
geometry and the modified wheel may be displayed in the wheel
view, allowing the operator to compare his/her modifications
to the ideal wheel shape.

15

The system can then automatically generate the changed flute
geometry that would be produced by the modified wheel
geometry. The changed flute geometry is displayed to the
operator superposed to the originally specified flute
20   geometry, again allowing the operator to compare the changed
flute shape to the originally desired flute shape.

        The operator can then modify the flute geometry
again to closer match the desired flute shape. The inverse-
25   solving module again automatically generates a new wheel
geometry for grinding a flute in accordance with the modified
flute geometry. The newly generated wheel geometry is again
displayed in the wheel view, superposed on to the previously
modified wheel, allowing the operator to compare the newly
30   generated wheel with the previously modified wheel.
If necessary, the process can be repeated until a wheel
geometry is generated that can produce a flute with a
substantially constant hook or rake angle over a range of
diameters as well as can conveniently be used to dress a
35   grinding wheel.

        According to a still further aspect of the

invention, there is provided a method and system for
generating a wheel geometry for a grinding wheel for grinding
a flute surface with a substantially constant hook or rake
angle over a range of diameters, wherein a wheel geometry for
5   a grinding wheel for grinding a flute surface with a constant
hook or rake angle is generated by an inverse solving module
using a flute geometry for the required flute surface,
wherein parameters for the wheel geometry and flute geometry
are able to be modified, and wherein an iterative method is
10   used to generate from a modified flute geometry a new wheel
geometry for a grinding wheel for grinding a flute surface
with a substantially constant hook or rake angle over a range
of diameters.

15   According to still a further aspect of the present
invention there is provided a method and system for
generating a wheel geometry for a grinding wheel for grinding
a real cutting surface of a machine tool, wherein a wheel
geometry for a wheel for grinding a desired cutting surface
20   is generated by an inverse solving module using a cutting
surface geometry for the desired cutting surface, wherein
parameters for the wheel geometry and cutting surface
geometry are able to be modified, and wherein an iterative
method is used to generate a new wheel geometry for a
25   grinding wheel for grinding the real cutting surface.

          A preferred embodiment of the present invention
will now be described, by way of example only, with reference
to the accompanying drawings, in which:
30

          Figure 1 is a schematic perspective view of a
grinding wheel of a CNC tool and cutter grinding machine
operating on a work-piece to grind the flute surface of a
blade of a cutting tool;
35

          Figure 2 is a schematic perspective view similar to
that of Figure 1 with the CNC tool and cutter grinding

machine operating on a stepped work-piece to grind a flute
surface, which provides substantially constant hook or rake
angle over a range of diameters.

5   Figure 3 is a schematic block diagram of the
control system for a CNC tool and cutter grinding machine in
accordance with the invention;

          Figure 4 is a cross-section through a flute of a
10   cutting tool having a constant hook or rake angle over a
range of diameters;

          Figure 5 is an enlarged view of part of the flute
cross-section of Figure 4; and

15

          Figure 6 is a block diagram showing procedural
steps of the method of the present invention, and

          Figure 7 is a flow chart showing an iterative
20   method for generating a wheel geometry for grinding a flute
surface with a substantially constant hook or rake angle.

          Referring to Figure 1 there is shown a grinding
wheel 1 of a CNC tool grinding machine operating on a
25   cylindrical work-piece 2 rotatable about a central
longitudinal axis of rotational symmetry S in order to grind
a flute surface 3 of a blade with a smooth helical cutting
edge. The grinding wheel 1 is substantially disc-shaped and
is rotatable about a central axis of rotation C. The grinding
30   wheel has a peripheral grinding edge 4.

          The grinding wheel is movable in an axial direction
A and a circumferential direction B relative to the workpiece
2 to grind the flute surface 3 of a blade which features a
35   cutting edge 5. In a rotary cutting tool formed from the
workpiece 2, the cutting tool usually has a plurality of
helical blades, each featuring a flute surface 3 and each

with a cutting edge 5 forming a leading edge of the tool. The
angle between the tangent of the leading face (e.g. flute) in
a radial direction and the surface normal to the machined
work-piece surface is usually called the rake angle or hook

5   angle.

CNC tool grinding machines nowadays have five or
more programmable axes, which are used to program a path for
the motion of the grinding wheel during its operation on the
10   work-piece. The programmable axes may include physical axes
and virtual programmable axes or "soft axes" such as
disclosed in our Australian Patent No 665000. In the
particular case described with reference to Figure 1 above,
the movement of the grinding wheel in the axial direction A
15   and in the circumferential direction B relative to the
workpiece may be programmed in terms of the programmable axes
of the CNC machine which are not shown in Figure 1.

Conventional CNC grinding methods are generally not
20   capable of grinding flute surfaces with a constant rake or
hook angle extending over a range of diameters. This problem
is particularly prevalent in the case of Step Tools or
Profile Tools in which the diameter of the cutting profile
varies over the length of the tool either continuously over a
25   range, such as illustrated in Figure 2, or in discrete steps.

Figure 2 shows a workpiece 2 and grinding wheel 1
similar to Figure 1, and corresponding reference numerals
have been applied to corresponding parts. Figure 2 differs
30   from Figure 1 in that the work-piece has an end section 6 of
lesser diameter, an opposite end section 7 of greater
diameter and an intermediate section 8 of varying diameter.
When using conventional methods for grinding flute surfaces 3
on a tool grinding machine, the rake or hook angle of the
35   flute varies in the intermediate region 8 of varying
diameter, so that the resultant rake angle in end section 6
differs from that in end section 7.

Figure 3 shows a control system for a CNC tool
grinding machine in accordance with the invention. As in a
conventional CNC machine, the control system has a
5   programmable control unit (PCU) 10 including parameter input
means 12, which may be in the form of a keypad, and a path
generator 14 for generating a programmed path for a grinding
wheel 1. The CNC machine may also include a trajectory
interpolator and position controller module 16 and one or
10   more actuators 18 for moving the grinding wheel 1 relative to
a workpiece.

The control system of Figure 3 differs from
conventional CNC tool grinding machines in that the parameter
15   input means 12 enables constant hook cross-section parameters
to be defined and input to the PCU 10 in addition to flute
twist parameters and wheel radius, phase angle and pivot
angle parameters.

20   In addition to the path generator 14, the
programmable control unit 10 also includes a three-
dimensional (3D) flute geometry generator 13 and an inverse
solving module 15. This module 15 calculates the required
wheel geometry for the given 3D flute geometry with constant
25   hook or rake cross section and the programmed path for the
grinding wheel. The wheel geometry data is then passed to a
wheel dressing machine 17 which produces the required wheel
profile on the grinding wheel 1. The wheel dressing machine
17 may be external to, or integrated with, the CNC tool
30   grinding machine. If the dressing machine is external to the
CNC tool grinding machine, the wheel is mounted on the CNC
machine after the dressing operation.

One preferred method of programming a CNC grinding
35   machine to grind a flute surface, which maintains a constant
rake angle over a range of diameters will now be described
with particular reference to Figures 4 to 6. Figures 4 and 5

show the cross-section of a flute having a constant hook or rake angle over a range of diameters. The steps of the preferred procedure are given below.

5   The cross-section geometry of the flute surface is specified (Steps 20 and 22 in Figure 6), typically featuring two distinct sections R and W in Figure 4. The section R closest to the cutting edge is the region of constant hook or rake angle and subject of this invention. The other section W

10   adjoins the first section and covers the remainder of the flute cross-section. Both these curves can be described as parametric curves.

          $c\_i(t) = (y(t), z(t))$, i = r,w, where $y(t)$, $z(t)$,

15   are the co-ordinates defining the points of each curve section. Curve $c\_r(t)$ is defined in such a way, that for any given parameter t, the tangent T to the curve point at that parameter forms an angle alpha ( ) with the radius to that curve point, which is equal to the specified rake angle. This

20   is shown in Figure 5 in which the rake angle alpha ( ) is the same at all points in section R.

          The flute twist parameters are specified (Step 24), typically these comprise the axial distance over which the

25   cross section will be rotated one full turn, or the angle between the cutting edge's tangent and that tangent's component in the axial-radial plane of the cutting tool. The first parameter is usually called the "Lead", the latter is usually called the "Helix Angle" of the cutting tool.

30

          The machine path parameters are specified (Step 26), these are typically the desired wheel radius, the pivot angle and the phase angle. The pivot angle describes a rotation of the wheel about the wheel plane axis, which is an

35   axis normal to both the wheel and the cutting tool axes. The phase angle describes the rotation of the flute cross-section about the cutting tool's axis, measured relative to the wheel

plane axis.

The flute cross-section of the cutting tool is placed in the x=0 plane (Step 22). Beginning from this position, the cross-section is extruded along the cutting tool axis according to the twist specification (Step 28). This geometric extrusion results in the 3-dimensional surface, which describes the desired surface of the cutting tool flute (Step 30).

A transformation function is derived (Step 32) from the constant hook cross-section parameters 22, the flute twist parameters 24 and the machine path parameters 26. The transformation function mathematically describes the machine path 34. For flute grinding, this path is typically a combined motion of the wheel and cutting tool in two axes. The wheel, which is positioned at a distance from the cutting tool axis is simultaneously moved along the cutting tools axis, while the cutting tool is rotating about its own axis.

Both the transformation function 34, describing the machining path 34 and the 3-dimensional flute geometry 30 are passed into the inverse solving module 15. This module calculates the required wheel geometry 36 and machine settings 38, according to the transformation function and 3-dimensional flute surface.

The wheel geometry is passed to the dressing machine 17, which produces the required wheel profile on a physical grinding wheel 1.

The CNC tool grinding machine is programmed with the machine settings output 38 from the inverse solving module 15 and the workpiece is ground 40, to produce a milling cutter with a flute having a constant hook or rake angle over a range of diameters 42.

Referring to Figure 7, there is shown a flow chart
of an interactive, iterative process for use in the present
invention for generating a wheel geometry for grinding a
flute surface with a substantially constant hook or rake
5   angle. The iterative process may be used when the wheel
geometry 36 generated for grinding a flute surface with a
constant hook or rake angle is not readily usable for
dressing a grinding wheel 1 on the wheel dresser 17.

10   Figure 7 is similar to Figure 6 and corresponding
reference numerals have been applied to corresponding
parts/steps of the process. Figure 7 differs from Figure 6 in
that after the wheel geometry is generated 36 by the inverse
solver 15 and displayed, the operator is given the option to
15   determine if the wheel geometry is suitable for dressing 54
and modify the wheel geometry, if it is not suitable for
dressing. If the wheel geometry is suitable, it is passed to
the wheel dresser 17 for dressing a grinding wheel 1.

20   If the operator determines that the wheel geometry
is not suitable for dressing a grinding wheel, the operator
may modify the wheel geometry 58. This may be achieved by the
user interactively altering the display of the wheel geometry
56. The modified wheel geometry 58 is then input in to a
25   forward solving module 60. This forward solver calculates the
flute cross-section 62, which would be produced by the
modified wheel geometry 58. This generated flute cross-
section 62 is displayed to the operator.

30   The operator determines, whether the generated
flute cross-section is acceptable 64. If it is acceptable,
the generated flute cross-section is fed back 22 into the
inverse solving loop, which will generate a wheel geometry 36
identical to that modified by the operator 56. Hence, the
35   iterative loop terminates 54, because the solved wheel
geometry 36 is the same as the previously modified wheel
geometry 56. The wheel geometry is passed to the wheel

dresser 17, and the physical wheel is dressed 1.

5   If the operator determines that the flute cross-
section 62, which would be generated by the modified wheel
geometry 58, is not acceptable 64, he can modify the flute
shape 66 to create an acceptable flute shape. The modified
flute shape is then fed back 22 into the inverse loop. The
inverse loop generates a new wheel geometry.

10   If the new wheel geometry is suitable, it may be
passed to the wheel dresser 17 for dressing a grinding wheel.
If it is again unsuitable for wheel dressing, the iterative
process may continue with the operator again modifying the
wheel geometry 56, the forward solver 60 generating a new
15   flute cross-section 62, according to the modified wheel
geometry 58 and, if necessary, the operator also modifying
the generated flute geometry 66.

          The present invention as described above thus
20   provides an effective method and system for generating a
wheel geometry for a grinding wheel to be dressed so that it
can be used to grind a flute surface with a substantially
constant hook or rake angle over a range of diameters.
Further, if the wheel geometry is not suitable for dressing a
25   grinding wheel, the iterative method described above can be
used to generate a wheel geometry which is an approximation
of the ideal wheel geometry for grinding a flute surface with
a constant hook or rake angle.

30   It will be appreciated that various modifications
and alterations may be made to the preferred embodiment of
the system and process described above with reference to the
drawings or that sub-systems or -processes may be extracted,
used in isolation or be integrated in systems or processes
35   not described in this patent without departing from the scope
and spirit of the invention.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1.   A method of grinding a surface of a flute on a
cutting tool over a range of tool diameters using a grinding
5   machine having a rotatable grinding wheel that is adapted to
move relative to the cutting tool, the method including:
            determining a machine path of the grinding
wheel; and
            rotating the grinding wheel and moving it
10 along the machine path to grind a flute surface having a
substantially constant rake angle.

2.   The method according to claim 1 comprising:
determining the three-dimensional geometry of the flute
15 surface on the cutting tool, the flute surface having a
substantially constant rake angle;
calculating a required geometry for the grinding wheel
according to the calculated machine path and three-
dimensional flute geometry; and
20 dressing the wheel to the required wheel geometry.

3.   The method according to claim 2 comprising
inputting geometry parameters of the cutting tool to
calculate the three-dimensional flute geometry of the flute
25 surface.

4.   The method according to claim 3, wherein the
geometry parameters include the cross section dimensions of
the flute and twist parameters of the flute.
30

5.   The method according to any one of claims 2 to 4,
comprising using machine path parameters and geometry
parameters of the cutting tool to calculate the machine path.

35 6.   The method according to claim 5, wherein the
machine path parameters include wheel radius and pivot angle
of the grinding wheel, and phase angle of the cutting tool

relative to the grinding wheel.

7.   The method according to any one of claims 2 to 6, comprising calculating machine settings of the grinding machine according to the three-dimensional geometry of the flute surface and the calculated machine path.

8.   The method according to any one of claims 2 to 7, further comprising modifying the wheel geometry and/or flute shape until the wheel geometry is suitable for dressing a grinding wheel, thereafter dressing the grinding wheel to the modified wheel geometry.

9.   A method of operating a computer numerically controlled (CNC) grinding machine to grind a surface of a flute of a cutting tool, the grinding machine having at least one rotatable grinding wheel moveable relative to the cutting tool, said method including programming the CNC machine with a path for the grinding of the flute wherein said method produces a flute geometry, which maintains a substantially constant rake angle over a range of cutting tool diameters.

10.   The method according to claim 9 wherein the method includes calculating a wheel geometry of the grinding wheel required to grind a flute surface with a substantially constant rake angle, dressing a grinding wheel in accordance with the calculated wheel geometry, and grinding the cutting tool with a dressed grinding wheel in accordance with a programmed path generated by the CNC grinding machine.

11.   The method according to claim 10, wherein the grinding wheel geometry is calculated from a three-dimensional model of the flute geometry for a flute surface with the required constant rake angle in an inverse solving module.

12.   The method according to claim 11 comprising feeding

the inverse solving module with data representing the programmed path for the grinding wheel and calculating machine settings for controlling movement of the grinding wheel along the program path to grind the flute surface with
5   a substantially constant rake angle.

13.   The method according to any one of claims 9 to 12 including entering constant rake cross-section parameters into the input of a programmable control unit of the CNC
10   machine.

14.   The method according to claim 13 comprising entering flute twist parameters and machine path parameters including wheel radius, phase angle and pivot angle into the
15   programmable control unit.

15.   The method according to claim 14 comprising using the constant rake cross-section parameters to generate flute cross-section data and calculating the three-dimensional
20   flute geometry from the flute cross-section data and the flute twist parameters.

16.   The method according to claim 15, comprising calculating the program path from the constant flute cross-
25   section parameters, the machine path parameters and the flute twist parameters.

17.   A cutting tool produced by the method of any one of claims 1 to 16.
30
18.   A cutting tool comprising a tool body having varying diameters, the tool body defining a helical flute surface wherein the flute surface is produced by a grinding process on a CNC grinding machine to provide a substantially
35   constant rake angle over all diameters of the cutting tool.

19.   A computer numerically controlled (CNC) grinding

machine for grinding cutting tools, the machine including a
rotatable grinding wheel that is adapted to move relative to
the cutting tool to grind a flute surface in the tool, the
machine being programmed with at least one path for the

5   grinding wheel which is calculated to grind said flute
surface maintaining a substantially constant rake angle over
a range of diameters of the flute surface.

20.   The CNC grinding machine according to claim 19
10   including input means for entering flute cross-section
parameters into a programmable control unit of the machine.

21.   The CNC grinding machine according to claim 20,
wherein the programmable control unit has the capabilities to
15   receive flute twist and machine path parameters including
wheel radius, phase angle of the cutting tool relative to the
grinding wheel, and pivot angle of the grinding wheel.

22.   The CNC grinding machine according to either claims
20   20 or 21, wherein constant rake parameters are used to
generate flute cross-section data and the 3-D flute geometry
is calculated from the flute cross-section data and the flute
twist parameters.

25   23.   The CNC grinding machine according to claim 22
wherein the programmed path is calculated from the constant
rake parameters, the flute cross-section parameters, the
machine path parameters and the flute twist parameters.

30   24.   The CNC grinding machine according to any one of
claims 19 to 23, wherein the machine includes dressing means
to dress the grinding wheel to a required wheel profile.

25.   A method of generating a required wheel geometry
35   for dressing a grinding wheel for grinding a flute surface
having a substantially constant rake angle over a range of
diameters, said method including the steps of,

generating a three-dimensional (3-D) flute geometry
for the required flute surface,

         generating a programmed path for the grinding wheel
to grind the flute surface, and

5   calculating the required wheel geometry for the
grinding wheel from the 3-D flute geometry and the programmed
path.

26.   The method according to claim 25 including the step
10 of generating a two-dimensional (2-D) flute cross-section
geometry, providing for the constant rake angle.

27.   A computer program for use with a computer
numerically controlled (CNC) grinding machine for grinding
15 cutting tools, the computer program comprising flute geometry
generating means to generate three-dimensional flute geometry
data for a flute surface having a substantially constant rake
angle over a range of tool diameters, path generating means
for generating a program path for a grinding wheel to grind
20 said flute surface with the substantially constant rake
angle, and inverse solving means for calculating the required
wheel geometry for the grinding wheel to grind said flute
surface with the substantially constant rake angle over a
range of tool diameters.
25

28.   A method and system for generating a wheel geometry
for a grinding wheel for grinding a real cutting surface of a
machine tool, wherein a wheel geometry for a wheel for
grinding a desired cutting surface is generated by an inverse
30 solving module using a cutting surface geometry for the
desired cutting surface, wherein parameters for the wheel
geometry and cutting surface geometry are able to be
modified, and wherein an iterative method is used to generate
a new wheel geometry for a grinding wheel for grinding the
35 real cutting surface.

29.   A method and system for generating a wheel

geometry for a grinding wheel for grinding a real flute surface with a substantially constant rake angle over a range of tool diameters, wherein a wheel geometry for a wheel for grinding a desired flute surface with a constant rake angle

5   is generated by an inverse solving module using a flute geometry for the desired flute surface, wherein parameters for the wheel geometry and flute geometry are able to be modified, and wherein an iterative method is used to generate a new wheel geometry for a grinding wheel for grinding the

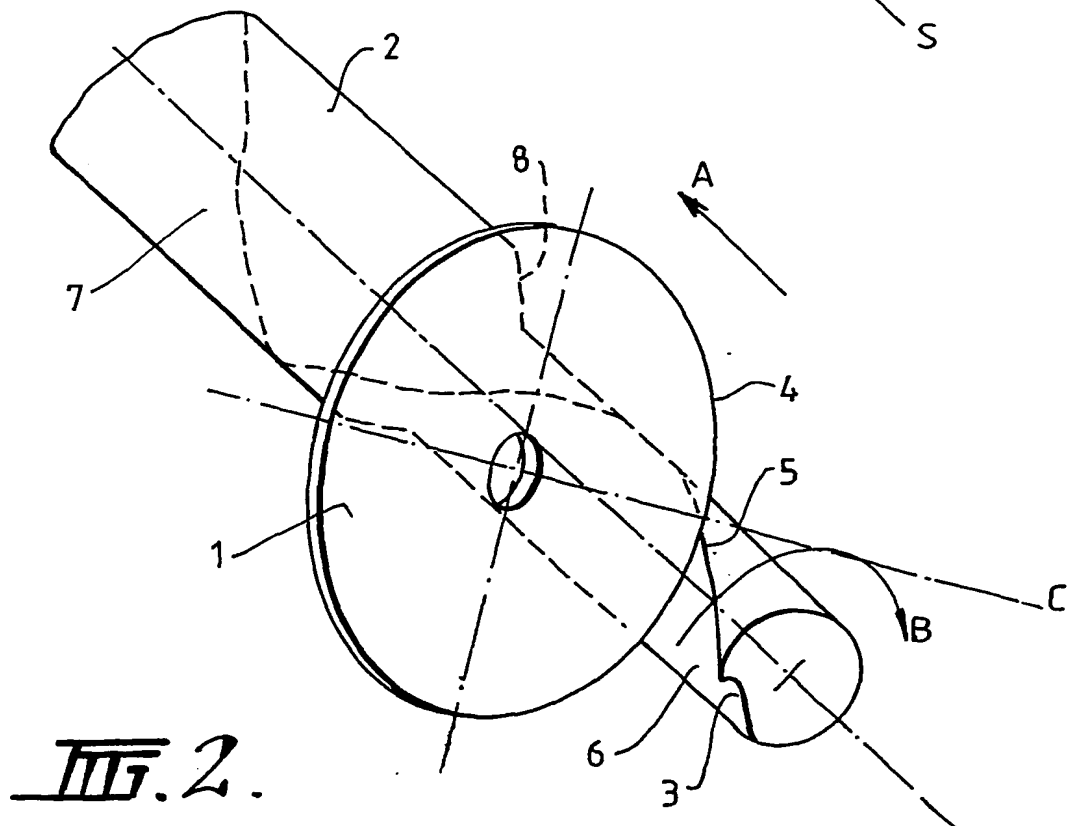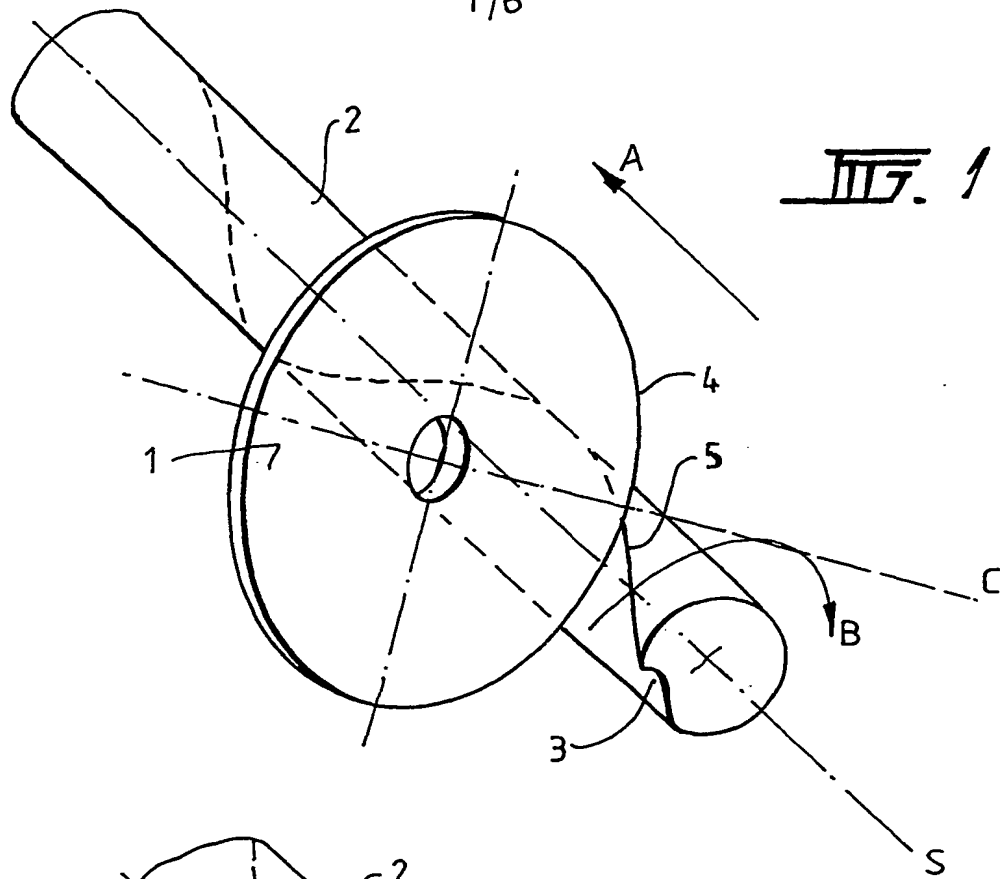10   real flute surface with a substantially constant rake angle over a range of tool diameters.

30.   The method and system of claim 29 wherein the iterative method comprises modifying the flute geometry if

15   the wheel geometry is unacceptable and/or modifying the wheel geometry if the flute geometry is unacceptable until both geometries are acceptable.

20

1/6

FIG. 1.

FIG. 2.

PARAMETER INPUT MEANS — 12

3D FLUTE GEOMETRY GENERATOR — 13

PATH GENERATOR — 14

10

INVERSE SOLVING MODULE — 15

WHEEL DRESSER — 17

TRAJECTORY INTERPOLATOR AND POSITION CONTROLLER — 16

ACTUATOR(S) — 18

GRINDING WHEEL — 1

𝕱𝕚𝕘. 3.

FIG. 4.

FIG. 5.

4|6

FIG. 6.

MODIFY FLUTE
X-SECTION

66

NO

FLUTE X-SECTION
ACCEPTABLE?

64

YES

22

FLUTE
X-SECTION

28

GENERATED FLUTE
X-SECTION
(DISPLAYED)

62

30

⊙

3D FLUTE
GEOMETRY

FORWARD
SOLVER

60

MODIFIED-
WHEEL
GEOMETRY

58

56

MODIFY WHEEL
SHAPE

FIG. 7a

```
┌─────────────────┐
│  CONSTANT HOOK  │
│    X-SECTION    │
│   PARAMETERS    │
└─────────────────┘
      20

┌─────────────────┐                    ┌─────────────────────┐
│   FLUTE TWIST   │          26        │  WHEEL RADIUS,      │
│   PARAMETERS    │                    │  PHASE ANGLE,       │
└─────────────────┘                    │  PIVOT ANGLE        │
      24                               └─────────────────────┘

                         ⊙ 32

                    ┌──────────┐
                    │   PATH   │  34
                    └──────────┘

              ┌──────────────────┐
              │  INVERSE SOLVER  │  15
              └──────────────────┘

              ┌──────────────────┐
              │ GENERATED WHEEL  │
              │    GEOMETRY      │  50
              │   (DISPLAYED)    │
              └──────────────────┘

                  ╱╲
                 ╱  ╲
         NO    ╱ IS WHEEL╲
     ◄────────╱ GEOMETRY O.K.╲   54
              ╲FOR DRESSING?╱
                 ╲        ╱
                  ╲  ╱
                  YES

         ┌────────────┐         ┌──────────┐
         │   WHEEL    │   17    │  WHEEL   │  1
         │  DRESSING  │────────►│          │
         └────────────┘         └──────────┘
```

$\overline{\Pi\Pi\Pi}.76$

A.	CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]:   B24B 17/00, 19/04

According to International Patent Classification (IPC) or to both national classification and IPC

B.	FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: B24B 17/00, 19/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C.	DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99/43469 A (ORMCO CORPORATION) 2 September 1999. Whole document	1-27
A	DE 2629130 A (JUNKER ERWIN) 12 January 1978. Whole document	1-27
A	US 4890419 A (ZANG) 2 January 1990. Whole document	1-27

☐ Further documents are listed in the continuation of Box C   ☒ See patent family annex

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2001	**1 9 NOV 2001**
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **SARAVANAMUTHU PONNAMPALAM** Telephone No : (02) 6283 2070

Form PCT/ISA/210 (second sheet) (July 1998)

3NSDOCID: <WO   0220216A1_I_>

INTERNATIONAL SEARCH REPORT	International application No.
	PCT/AU01/01116

Box I	**Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos :

   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos :

   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos :

   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II	**Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

  1. Claims 1-27 are directed to a cutting tool and method of grinding a surface of a flute on the cutting tool.

  2. Claims 28-30 are directed to a metthod and systems for generating wheel geometry for a grinding wheel.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:1-27

Remark on Protest	☐ The additional search fees were accompanied by the applicant's protest.
	☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1)) (July 1998)

Supplemental Box
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No: II

1.   Claims 1-27 are directed to a cutting tool and method of grinding a surface of a flute on the cutting tool including having a machine path of the grinding wheel to grind a flute surface having substantially constant rake angle.

2.   Claims 28-30 are directed to a method and systems for generating wheel geometry for a grinding wheel including an iterative method is used to generate new wheel geometry for grinding the real cutting surface.

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	43469 A	NONE					
DE	2629130 A	NONE					
US	4890419 A	DE	3706948 A	EP	281025 A	JP	1228763 A

END OF ANNEX